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SPACE ODYSSEY OF TOMORROW —

A TRIP TO MARS

By Robert Jastrow

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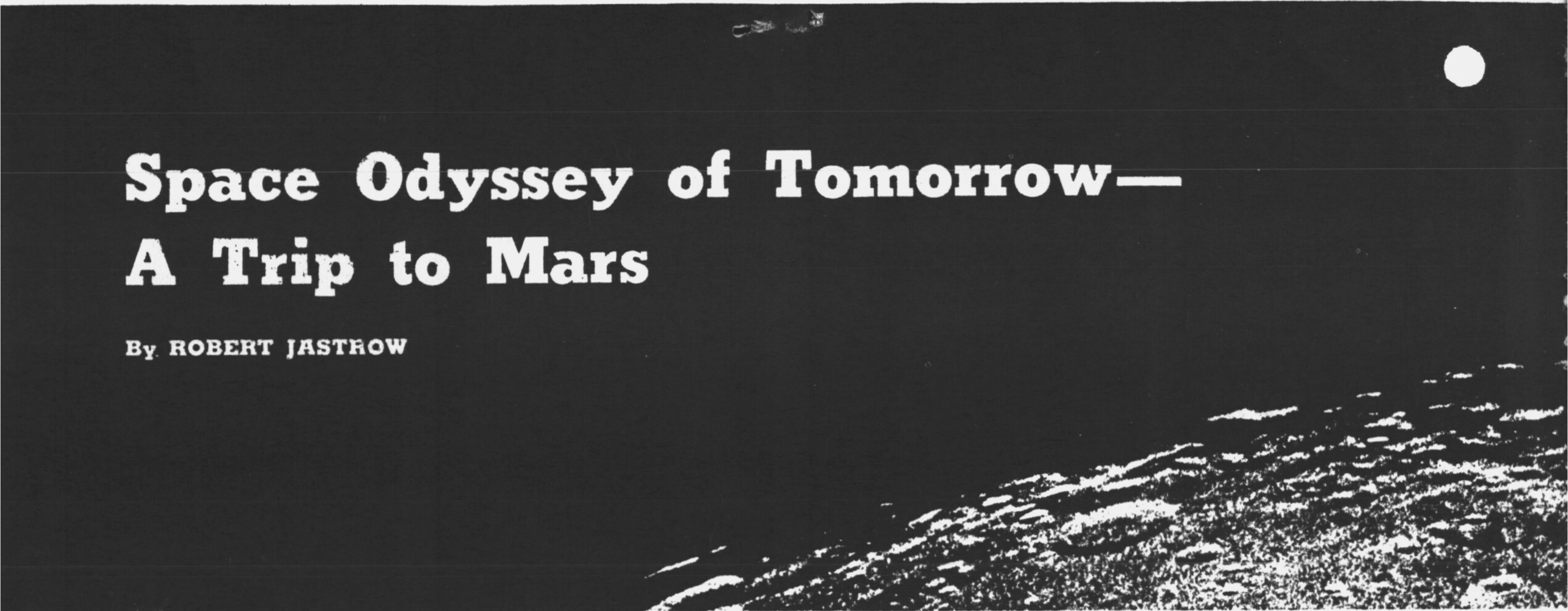


Space Odyssey of Tomorrow— A Trip to Mars

By ROBERT JASTROW

THE earth began its existence 4.6 billion years ago, circling around the newborn sun. Formed out of inert atoms of gas and grains of dust, our planet was surely a sterile body of rock at the beginning. The waters of the primitive oceans were devoid of life; their waves lapped at barren shores, uncarpeted by vegetation. Yet today plants grow everywhere; 20,000 kinds of fishes inhabit the seas; the continents crawl with a million varieties of animal life; three billion human beings cover the planet.

How did it happen—this transformation of inanimate matter into man? Is the appearance of intelligent life on a planet a miracle, or is it a commonplace event? According to a widely held view in the scientific community, we have appeared on the scene as the product of an unbroken sequence of events, extending over 10 billion years, in which the universe expanded and cooled, stars were born and died, the sun and the earth were formed, and, finally, life arose on the earth. The synthesis of scientific knowledge indicates that a single chain of cause and effect links the world of the atom to the world of life.

But one key element is still missing. That element can never be supplied on the earth, no matter how clever scientists may become. In this solar system, the missing element—if it exists—is likely to be found only on Mars. For that reason, the exploration of the red planet—first by instruments and then by man—will be the most important objective of planetary science for many decades to come.

ROBERT JASTROW is director of the NASA Institute for Space Studies. This article is based upon his book "Red Giants and White Dwarfs" and "Beyond the Moon," written with Nicholas Panagakos.

THE scientific story of the origin of life begins with atoms of the primeval element, hydrogen, which swirled through outer space in vast clouds. These clouds were the raw stuff out of which stars, planets and men were made. Occasionally, the atoms of a cloud were drawn together by the attractive forces of gravity; with the passage of time the cloud contracted to a small, dense globe of gas; heated by self-compression, it rose in temperature until, at a level of some millions of degrees, its center burst into nuclear flame. Out of such events, stars were born.

Within the newborn star a series of nuclear reactions set in, in which all the other elements of the universe were manufactured out of the basic ingredient, hydrogen. Eventually, these nuclear reactions died out and the star's life came to an end. Deprived of its resources of nuclear energy, it collapsed under its own weight, and in the aftermath of the collapse an explosion occurred, spraying out to space all the materials that had been created within the star during its lifetime.

Later in the history of the galaxy, other stars were formed out of clouds of hydrogen which had been enriched by the products of these explosions. The sun is one of these stars; it contains the debris of countless explosions dating back to the earliest years of the galaxy. The planets also contain this debris; the earth, in particular, is composed almost entirely of it. We owe our corporeal existence to events that took place billions of years ago, in stars that lived and died long before the solar system came into being.

When the earth was formed, it must have been barren, but within one billion years or so life appeared on its surface. How can we explain this fact? If we choose to restrict the inquiry to the boundaries of science, three discoveries of the last few decades suggest a tentative answer. *First*, the biologists have discovered that certain molecules—amino acids and nucleotides — are the essential building blocks of all living creatures. *Second*, chemists have created these molecules in the laboratory, out of the kinds of chemicals that existed in the atmosphere and oceans of the primitive earth. *Third*, a link has been discovered between the atoms and molecules of the physical universe and the complex organisms of the living world. Called the virus, it lives on the borderline between inanimate matter and life. Its existence gives credibility to the notion that life can evolve out of nonliving chemicals.

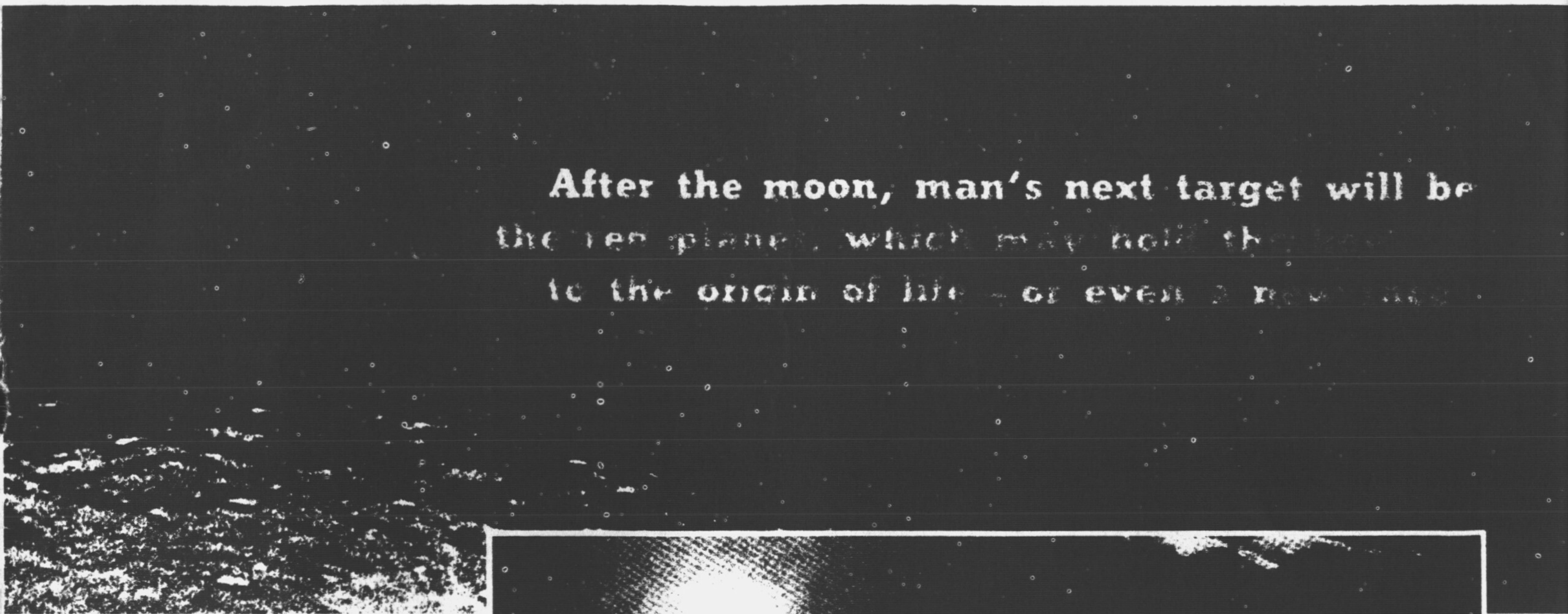
The imagination of the scientist has seized on these items of evidence, and has fashioned out of them a picture of the origin of life on the earth. No living form existed on our planet in its infancy; the atmosphere was filled with a noxious mixture of ammonia, methane and other gases; peals of thunder rumbled across the sky; flashes of lightning occasionally illuminated the surface, but no eye perceived them; minute amounts of amino acids and nucleotides were formed in each flash, and gradually these critical molecules accumulated in the earth's oceans; collisions occurred now and then, linking small molecules into larger ones. During the course of a billion years, the concentration of complex molecules increased; eventually, the threshold was crossed from inorganic matter to the living organism.

ACCORDING to this story, life can appear spontaneously on any comfortable planet, and evolve into complex beings, provided sufficient time is available. What is the probability of this happening?

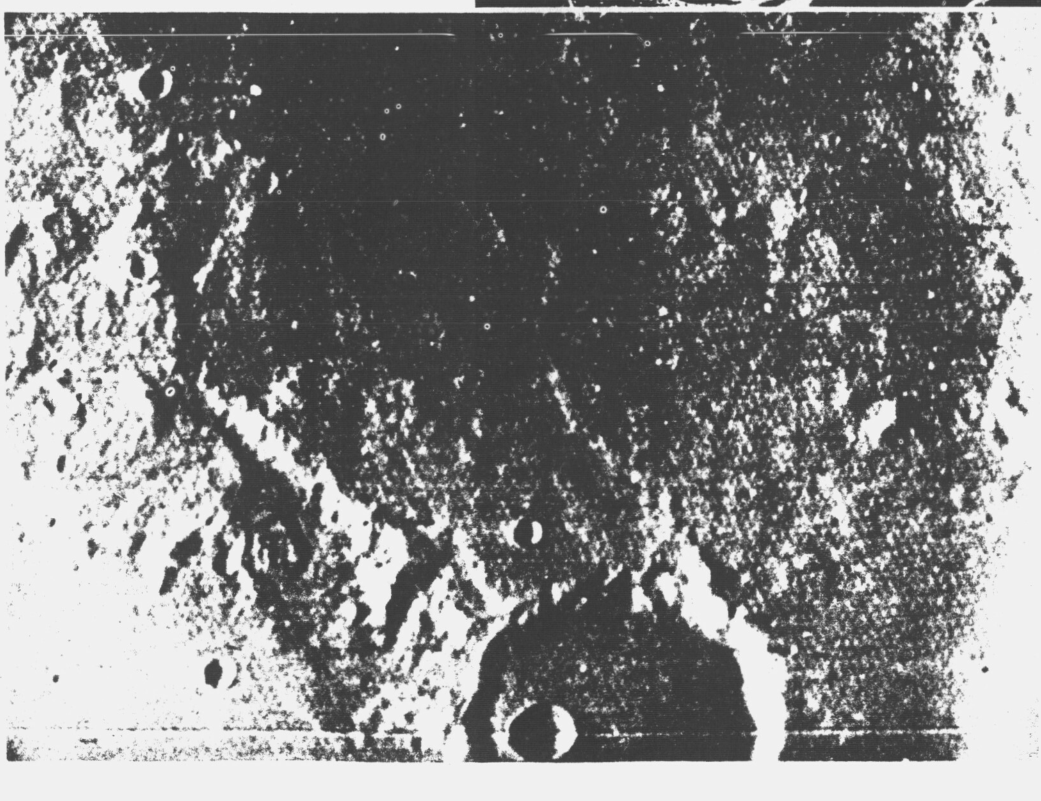
Neither theoretical reasoning nor laboratory experiments have yielded an answer to this question. Nature required several hundred million years of ceaseless random experimentation to discover the chemical pathways to life on the earth, and I suspect that the scientist's ingenuity will never be equal to the task of imitating her in any finite span of time. We will probably never learn in the laboratory the probability of the spontaneous generation of life out of inanimate matter. We will never learn in the laboratory whether we are alone in this corner of the universe, or dwellers on a commonplace planet in a galaxy teeming with life.

The galaxy to which we belong contains 100 thousand million other stars, many of which are surrounded by families of planets, according to the best astronomical evidence. Ten thousand million other galaxies, each containing 100 thousand million stars, and probably a like number of planets, are within range of our largest telescopes. In this multitude of planets there must be some which resemble the earth very closely. Let such planets be relatively few in number; let them be as rare as one

After the moon, man's next target will be the red planet, which may hold th[illegible] to the origin of life – or even a n[illegible]



That's Mars? Indeed it is, from assorted points of view. Above, as seen peering over the rim of the moon. Right, as envisioned back in 1956 by Chesley Bonestell, the well-known space artist, earthlings atop a peak on Mars gaze across one of the planet's supposed canals, which the artist sees as a fog-filled valley. Below, the surface of Mars as actually photographed by Mariner 6 last summer. The area covered is about 50 miles wide. The crater-pocked surface is suggestive of the moon. But it just possibly may not be entirely lifeless.



in a million—no matter: the number of earthlike planets will still be 100,000 *in our galaxy alone.* Can we maintain a belief in the uniqueness of life on the earth in the face of these numbers?

We can on the astronomical evidence alone, because all earthlike planets except ours could be barren bodies of rock. But *if* life is discovered on Mars, we can be sure that many of the earthlike planets in the universe are inhabited. Mars is dry, cold, and less favorable than the earth for the support of life, but not implacably hostile.* Life could exist in the harsh climate of Mars, and if it does, we will know that on planets with comfortable climates—similar to that on the earth — the chances of finding life are substantial.

But the discovery of *primitive* organisms on other planets would not diminish our sense of being alone in the universe. What is the likelihood that inhabited earthlike planets harbor intelligent life? Is there a chance that extraterrestrial beings have acquired a level of intelligence equal to, or greater than, ours?

Considering this question, we must reflect that our galaxy is believed to be about 10 billion years old. The earth is roughly five billion years old, and, therefore, was formed when the galaxy had already existed for five billion years. Thus, there must be many stars in the galaxy that are billions of years older than the sun. Around some of these older stars circle earthlike planets on which life may have evolved. If so, this life has existed for billions of years longer than life on the earth. When we reflect on the scientific advances of the past 20 years, we realize that the advances which will occur in another billion years are beyond our imagination. Consider the history of man: We have existed as a human species for barely two million years; modern science is only 300 years old; our ability to communicate over long distances by radio goes back only 60 years; it is a mere decade since we acquired the means of traveling in space. The period in which our scientific knowledge has developed is a narrow slice of time, sandwiched between billions of years of evolution that preceded the emergence of man and billions of years that lie before us in the lifetime of the solar system.

It is exceedingly unlikely that any society on another planet came into existence at the same moment of time, and developed at the same rate, so as to have arrived at precisely the same level of technology which we possess on the earth today. A difference of 100 years, which is infinitesimal in the lifetime of a star or planet, has produced enormous changes in the scientific knowledge of our society. Some extraterrestrial societies would be primitive in comparison with us; others, with an earlier start, would have surpassed our achievements a long time ago, reaching great heights of wisdom, or heights of scientific knowledge.

All these prospects hinge on the outcome of the search for life on Mars. There is another, more immediate significance to that search. If Martian organisms exist, they must be highly specialized for survival on a nearly water-free and airless planet. Doubtless they would present an unusual appearance; their colors, forms, internal arrangements and methods of reproduction might seem bizarre; the difference between plants and animals, as we know them, might be blurred. Nonetheless, this extraterrestrial life would have much to teach us about the nature of life on the earth, for the basic chemistry of Martian life—product of an independent line of evolution, and adapted to markedly diffferent conditions —probably would not be identical with the chemistry of terrestrial life. From the comparison between the two living structures, parallel but distinct, we would gain insights into the metabolism of all living organisms, including man, that we could not gain in decades of laboratory research on earth.

The search for life on Mars has already begun. Living organisms betray their existence by chemical changes they produce in their environment, which can be detected by remote-controlled instruments. In 1969 two Mariner spacecraft flew past Mars at a distance of a few thousand miles, carrying instruments capable of sensing some of the chemicals associated with life. One of these instruments measured infrared radiation in a region of wave lengths where the gas methane has characteristic absorption bands. Methane is released by decaying vegetation, but, being relatively unstable, it does not last very long in the atmosphere unless plants are present to continually renew the supply.

Methane was not detected, a negative result that seems to quench our hopes of finding Martian life. A New York Times editorial commented that the Mariner experiment "virtually closed the door to the possibility that life as known on earth exists on Mars." However, this conclusion was premature, for the instruments, never closer to the surface of Mars than 1,800 miles, could not detect methane if present in extremely small amounts. The limit on the sensitivity of the instruments corresponded to a concentration of one part per million of methane, which is about the same as the concentration of methane in the earth's atmosphere. Thus, a Mars flora could exist and be nearly as abundant as the vegetation on the surface of the earth, and still have escaped detection in this experiment.

Another Mariner instrument, designed for the detection of nitrogen, provided a second test for life on Mars. Nitrogen, like methane, is a product of the cycle of growth and decay in living organisms. Again, the instrument failed to indicate the presence of the critical gas. However, the smallest amount of nitrogen that the Mariner instruments could detect is approximately equal to the amount of nitrogen *of biological origin** in the earth's atmosphere. As in the case of the methane experiment, this experiment does not exclude the presence of life on Mars. It indicates only that life cannot be as abundant as, or more abundant than, life on the earth.

Manned landings on Mars are likely by the year 2000

A more sensitive test for life on Mars is planned for 1975. In that year, an improved version of the Mariner spacecraft will be launched, containing a package of instruments to be dropped on the surface of Mars as the main spacecraft flies by. According to one design, the landing craft will contain a long sticky string that will be thrown out across the landing site and then reeled back into the body of the craft, presumably with particles of Martian soil adhering to it. The particles will be deposited in culture dishes containing ingredients that make excellent food for terrestrial bacteria. This food is made up of atoms of carbon, nitrogen, oxygen and other elements. If microorganisms are present on Mars and their chemistry resembles that of bacteria on the earth, they will consume the food and multiply. The heart of the experiment lies in the fact that the carbon in the food is *radioactive* carbon, not the nonradioactive carbon normally found in nature. The radioactive carbon, if ingested by the Martian organisms, would be incorporated into the chemicals of their cells in the reactions that constitute the life processes of the organisms. In these reactions, some of the radioactive carbon would be combined with oxygen to make radioactive carbon dioxide. The radioactive carbon dioxide would be exhaled by the bacteria.

Adjoining the chamber with the culture dishes is a second chamber containing an instrument sensitive to radioactive substances. The second chamber is separated from the first by a filter through which no particle larger than a molecule of gas can penetrate. The food particles containing the original radioactive carbon cannot pass between the two chambers, but carbon dioxide gas can do so. The instrument will send a signal to the earth if it detects radioactivity. The receipt of this signal would indicate that a Martian microorganism had been eating the food containing radioactive carbon.

The experiment is ingenious, but it will work only if Martian life is similar to earth life in its basic chemistry. No one has been able to invent a plausible kind of life chemistry that is completely different from the carbon-based chemistry of earth life, but the failure probably reflects the limited imagination of the scientist, rather than a true limit on the number of chemical possibilities for life. For this reason, life on Mars may remain undetected until a manned expedition reaches the planet.

Manned landings on Mars are likely to occur by the end of the century. They will determine whether life exists on Mars, if the question has not been settled earlier by remote-controlled experiments. Manned exploration also will settle a question of equal importance for determining the probability of life arising out of nonliving chemicals: Is it possible that Mars is lifeless today, but was formerly the site of a rich variety of life? Martian life may have existed at one time and then been extinguished—like the dinosaurs on the earth—by a change in climate or some other adverse circumstance. In that case, fossil remains or molecular remnants of life—such as amino acids and nucleotides — will be found in the Mars crust. But the search for these fossils will be much more difficult than the search for living organisms. Insights derived from long experience guide the paleontologist in his hunt for fossiliferous deposits. The untutored eye can look squarely at an exposed fossil bed without recognizing it. A robot observer that successfully mimicked the skills of the paleontologist would be prohibitively expensive in comparison with the cost of transporting these specialists to the scene.

Chemical tests for trace amounts of molecules of bio logical origin are not as difficult to carry out by remote control. A completely automatic device for detecting amino acids — the molecules that make up proteins — already exists, and miniaturized versions suitable for the Mars flight are under development. The disadvantage of the automatic amino-acid analyzer is that it can do only the one job for which it was designed. Presumably, this job will be to test for the 20-odd specific amino acids that are found in terrestrial life, but dozens of other amino acids exist and

***Experiments have shown that plants can exist in the Martian climate, although they do not flourish. Cosmic-ray and ultraviolet radiations bombard Mars with an intensity that would be lethal to terrestrial life, but biologists have suggested ways in which Martian organisms could have evolved natural shields against these death rays.**

The single element essential for life as we know it is water. Living organisms can evolve out of nonliving molecules only if those molecules are dissolved in an ample supply of water, in which they can move freely and collide with one another again and again. Mars — unlike the moon — has a trace of the critical moisture on its surface, and no evidence exists to *exclude* the possibility that it has seen even wetter days in its past. Until detailed photographs are available from Mars-orbiting spacecraft, beginning in 1971, this fascinating question of early water on Mars remains open.

***Only a small part of the earth's atmospheric nitrogen is associated with life; 99.99 per cent came from the interior of the planet in volcanic gases, and would be present in the atmosphere even if the earth were lifeless.**

are equally likely to be found in life on another world. If the amino-acid analyzer gives a positive answer, we will know life exists or has existed on Mars. If the analyzer gives a negative answer, we will not know whether this means that there is no life on Mars, or that Mars life exists but is made up of different chemicals from earth life.

One answer to the problem would be the construction of an unmanned spacecraft that could collect samples of Mars soil and return them to earth laboratories. Such a machine would be a tour de force of space technology, one which could easily compare in cost to the direct expense of a manned Mars mission. Apart from the question of costs, the unmanned spacecraft is at a disadvantage because it cannot match the eye and brain of the trained scientist in selecting the most favorable place for the collection of life-bearing samples. As in the case of the search for fossils, the robot sample collector may be no less costly, and is certain to be far less productive scientifically, than the human observer transported to the scene.

BEFORE a manned Mars expedition can be attempted, we must achieve three advances over the Apollo flights. First, nuclear rockets must be built and flown; second, space flights lasting a year or more must become routine operations; third, lunar colonies must be established to practice the arts of survival on an alien planet. The first two developments will evolve independently of the preparation for the Mars mission because they are needed to lower the cost of future space operations—in particular, the commercial applications of satellites. A permanent lunar colony or observatory is independently required to reap the full scientific benefits of the pioneering Apollo flights.

The nuclear rocket is important because it is more efficient than the conventional chemical rockets used in the Saturn-Apollo system. If the best chemical rockets were used, a spacecraft suitable for carrying four men on the round trip to Mars would weigh three million to four million pounds. The spacecraft would be launched into earth orbit in several subunits and assembled there. A minimum of 12 Saturn 5 launches over several years would be required for this purpose. But if nuclear rockets were used, the weight of the Mars spacecraft could be reduced to 1.6 million pounds. The subunits of the spacecraft could be placed in orbit, prior to assembly, by no more than four to six Saturn5 rockets launched over a period of a year or so. The reduction in the cost and complexity of the operation would be enormous.

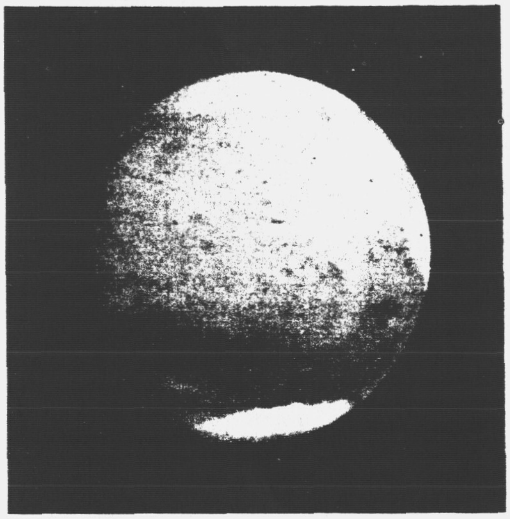
Why are nuclear rockets more efficient than chemical rockets? A chemical rocket works by burning a fuel containing liquid oxygen to produce a jet of hot gas. The Saturn5, for example, burns kerosene with liquid oxygen to produce a mixture of gases composed mainly of water vapor and carbon dioxide. These gases, roaring out of the nozzle of the rocket engine, constitute the enormous flame that is the most awesome feature of a Saturn5 launch.

The jet of hot gas, rushing out of the rear of the rocket at an average speed of 16,000 feet per second, pushes back on the rocket as it escapes, driving the rocket forward, just as the exhaust of a jet engine drives an aircraft forward.

The nuclear rocket works on the same principle: a jet of hot gas, escaping from the rear of the rocket, provides a forward thrust. But in this case, the jet of hot gas is created by bringing liquid hydrogen into contact with the white-hot surface of a nuclear reactor (whose presence gives the nuclear rocket its name). The heated hydrogen, now a gas at a temperature of 8,000 degrees Fahrenheit, jets out of the rear nozzle of the rocket engine at an average speed of 30,000 feet per second. It has this very high speed because hydrogen molecules are the lightest molecules known to man. In a chemical rocket, on the other hand, the jet is composed of molecules that are relatively heavy and hence travel at only about half the speed of the escaping molecules in the nuclear rocket. Pound for pound, therefore, a nuclear rocket derives twice as much forward impulse from its escaping jet as the chemical rocket does.

THE second critical element in the Mars flight—experience with year-long space sojourns—depends on the development of large earth-orbiting space stations. In these stations the Mars crew will practice the techniques of living and working for many months at a time in a zero-gravity environment. Plans are in an advanced stage for orbiting such stations in the nineteen-seventies.

The first-generation space station, planned for launch in 1972, will operate on a modest housing plan, using the empty third stage of a Saturn 5 as the astronauts' home in space.



Reality. Mars, as photographed by the Mariner 6 on its fly-past last summer. Unfortunately for romantics, not a sign of a canal.

Two Saturns will be launched, one carrying the crew in a regular Apollo command module and the other carrying their future home in space. The astronauts will link up with the Saturn third stage, occupy it, and set up housekeeping. The cargo will include construction materials, instruments and other gear needed to establish laboratories and living quarters in the empty tank for as many as nine astronauts. A crew might stay in this station as long as two months before returning to earth.

By the late nineteen-seventies, space crews will have moved out of the Saturn rocket "Quonset hut" and into better quarters. The second-generation space station would be assembled in orbit out of separately launched subunits. The assembly would begin with small crew quarters and grow as new ones were added. Each subunit, weighing about 50 tons, would probably be a cylinder 33 feet wide and 40 feet long. A station consisting of two or three subunits would house a total of 12 crew members and scientists for tours of duty lasting three to six months. The net living space for each man would be 1,000 cubic feet, about the same amount of room provided each crew member in a submarine.

These modular stations would grow to substantial size during the nineteen-eighties. New units could be added to provide a separate wardroom for dining and food preparation; a recreation and exercise area; a systems module to house the power, control and life-support systems; a docking and cargo-handling unit, which would permit the docking of spacecraft arriving from earth with supplies and equipment; and a storage module which would serve as a warehouse for food, spare parts and other materials.

By the end of the 20th century, the immense orbital platform that served as an interplanetary jumping-off place in the movie "2001: A Space Odyssey" may be a reality. It would be hundreds of feet across, weigh several million pounds, and be powered by atomic reactors. Such a platform would be able to accom-

Beyond Apollo 13

With the hazardous journey of Aquarius fresh in our memories, the question which everyone must now ask is: What human interests are served by the continuation of manned space flights?

In the short run, manned flights are needed to realize the full economic and scientific potential of space operations. There is gold in manned space flight—not on the moon, but in the application of our painfully acquired space capability to a number of highly practical enterprises. Commercial satellites and man-in-space are entirely separate operations at the moment, but the separation is not permanent. It is only a feature of the Model T era in space.

The first satellites devoted to commercial applications have been primitive affairs, containing simple equipment, and their replacement cost is not an unduly heavy burden. Within a few years, this will no longer be true. Large satellites will be placed in orbit, each one combining several vital functions. Ocean surveys from satellites are expected to increase the world's fishing catch by $2-billion a year. Just over the horizon is the use of satellites for prospecting for oil, gas and minerals, from which we should realize another $2-billion a year in royalties on U. S. deposits alone. Satellites will survey our atmosphere, lakes and rivers for evidence of pollution, and provide currently unavailable data needed for a large-scale attack on the pollution of air and water. All this can be done at a hudredth or thousandth of the cost per square mile of surveys from the ground or aircraft.

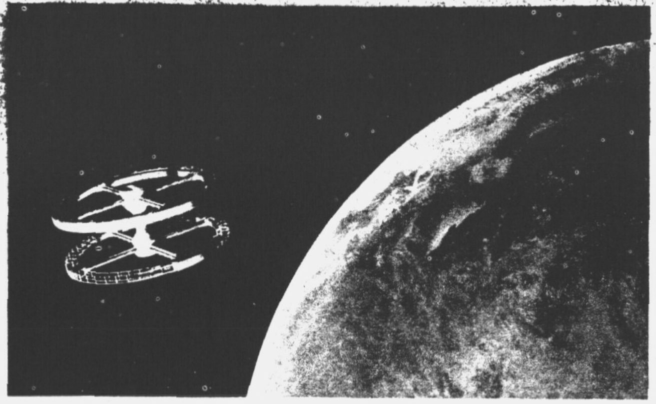
Most important—in terms of lives to be saved—is air-traffic control from hovering satellites, which should become a reality in the nineteen-seventies. It will not be feasible to permit one of these critically important devices to go off the air for a minute, or an hour or a day, because a transistor has malfunctioned.

Manned flights, based on the Saturn Apollo capability, are likely to prove the cheapest way of achieving a 100 per cent guarantee of uninterrupted satellite service. The space station and the space shuttle play critical roles in plans for these down-to-earth applications of manned space flight during the nineteen-seventies, and are almost certain to be developed regardless of the pace of planetary exploration.

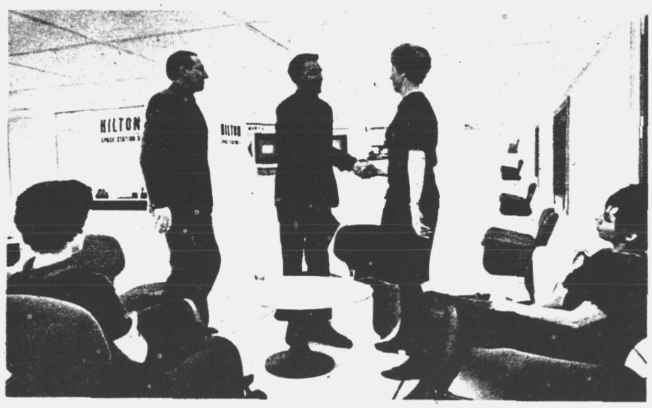
But beyond that consideration, manned flights to the planets will illuminate the most important scientific question to occupy the mind of man—the origin and uniqueness of intelligent life.—R. J.

modate 100 persons, including crew members, resident scientists and passengers in transit to the moon or Mars. It would be the third-generation space station.

At this stage, if not sooner, it is likely that space stations will be constructed on the principle of a rotation wheel several hundred feet in diameter, turning slowly and majestically on its axis once every minute or so to create the familiar comforts of gravity for its occupants. Artificial gravity will introduce many conveniences into space life. Domestic arrangements — housekeeping, eating, drinking and washing— as well as scientific work will be easier when feet are firmly planted on the floor and liquids stay in their place. Equally important, artificial gravity will diminish the medical hazard of returning to the earth's gravity after many months in orbit.



Fantasy? These two stills from the movie "2001: A Space Odyssey" are not too far removed from the author's sobersided prognostications. Above, a shuttle ship from earth (the planet at the right of the picture) nears a space station wheeling in orbit. Below, aboard the space station, astronauts break their journeys like travelers in a present-day airport lounge.



THESE are the nuts-and-bolts aspects of life in space. What are the human problems that must be faced during an extended stay in orbit? First, food, water and oxygen must be supplied at the rate of six pounds a day for each person, but this is not a major problem. A 12-man crew in orbit for six months requires 13,000 pounds of these materials, which is a modest addition to the weight of the space station itself.

The most vexing human problems lie elsewhere. How will the body respond to extended periods of weightlessness and to the strain imposed by the suddenly renewed pull of the earth's gravity when a mission ends? Creation of artificial gravity a fraction as strong as that on earth—by rotation of the space station—will ameliorate the problem but may not solve it. A vigorous exercise program in orbit will be a part of the answer. The workouts will depend on the resistance of stiff springs and elastic cords in place of gravity. One of the lifesaving components of the orbiting platform may be a small gymnasium containing equipment built around such devices.

Another critical area of human problems involves the psychological stresses that will result from confinement to limited quarters for months at a time, in a very small society and under unnerving physiological circumstances. It seems impossible to predict the nature of the reactions to this societally bizarre situation. Initial experience with extended space journeys may indicate that an individual cannot be relied on to maintain his emotional stability, no matter how careful the preflight selection tests for the space station are. Further experience may yield rules of thumb, giving the minimum crew size necessary to achieve a stable microsociety, as a function of living space provided for each person, length of stay in space and other factors. This is the least explored and most unpredictable aspect of extended space travel.

One particularly troublesome problem has already emerged in past experience with mountain-climbing and polar expeditions, whose members are usually divided between scientists with a primarily intellectual motivation and operating personnel with a practical orientation and experience in physically dangerous situations. Each group tends to be contemptuous of the values of the other, and intergroup contact is often avoided, although the hazardous nature of the expedition requires a very high level of cooperation for survival. The problem has not arisen in earth-orbit and lunar missions thus far, because all candidates for flight assignments, regardless of background, have been put through the same mill of rigorous preflight training routines, but the extra stresses of a two-year space voyage may make the conflict between scientists and crew a serious problem.

THE economic feasibility of the space station depends on the development of a rocket plane—called a space shuttle—that can carry men and cargo from earth to orbit and back at low cost, landing on standard jet runways. At present we throw away our rockets after a single use. The fare from New York to London would be quite high if airlines operated on this basis. The space shuttle will lower the cost of a round-trip ticket for the earth-moon trip to 4 cents a mile, about the same as trans-Atlantic fares.

According to one design, the space shuttle will look like a 727 jet with stubby wings, perched piggyback on a booster rocket similar in size and appearance to a 747. The combination will be launched nose-up from Cape Kennedy like present-day rockets. At an altitude of 30 miles and a speed of 10,000 miles per hour, the 727-sized shuttle will separate from the mother craft and climb into orbit for the rendezvous with the space station and transfer of passengers and cargo. Meanwhile, the booster rocket, piloted by its own crew, will dive into the lower atmosphere and start up auxiliary jet engines for a conventional landing on a 10,000-foot runway.

The shuttle will also be able to land on a standard airport runway after descending from orbit. The shuttle and booster rockets would follow similar maneuvers on re-entry: both would plow into the atmosphere belly-first and nose-up, at an angle of 60 degrees, rather than attempting to slice cleanly through the dense air. The purpose of the belly-first maneuver, as in the case of the re-entering Apollo capsules, is to present the largest possible area to the air, reducing speed as rapidly as possible, thus minimizing the length of time during which the craft is heated by air friction. At an altitude of 40,000 feet, the pilot will bring the nose of the plane down sharply and complete the descent in nearly level flight on auxiliary jet power.

The space shuttle will carry a crew of two plus 10 passengers or 25,000 pounds of cargo, either up into or down from orbit. The cargo bay will be sized to accommodate large commercial and scientific satellites.*

SMALL colonies will be established on the moon in parallel with the development of the space station and the space shuttle, partly for scientific observations but also to gain experience in living on a barren, hostile plane. The experience gained with the lunar colonies will be valuable to the crews of the manned expeditions to Mars during their planned stays of four to six weeks on the planet. The Mariner experiments have already told us enough about Mars to indicate that it resembles the moon in many respects, although it is not as hostile to man. If we can learn to survive on the moon, we will be confident of our ability to survive on Mars.

The bases established in the initial Apollo landings have been temporary. The astronauts have had no transportation other than their feet; their time on the moon has been measured in hours rather than months; and when they leave, the base is abandoned. But the Apollo bases are paving the way for semi-permanent lunar colonies. In later flights, unmanned lunar modules may deposit caches of supplies on the moon's surface, enough to maintain two men for two weeks. The manned landing would follow within a few weeks after the supply cache had been deposited. When the initial team departed, the base would be closed down, but it could be reactivated later.

A permanent lunar base may be established by the end of the nineteen-seventies, housing six to a dozen men who will rotate tours of duty, with earth leaves at six-month intervals. They will share living quarters insulated against the temperature extremes of the lunar day and night and shielded against bombardment by solar protons and ultraviolet rays. A 100-kilowatt nuclear reactor, of the type already in use at Arctic bases, will furnish power. By the turn of the century, a lunar colony of 50 or 100 men is possible. As experience increases, these communities may grow until they cover areas of many square miles.

When the nuclear rocket is available, and tours of duty in the lunar colony and the space station have become routine, the Mars expedition can get underway.

* * *

THE following description of a successful flight is based upon one NASA study among many that have received serious study.

Two ships will make the trip, flying buddy system. If either ship is disabled, its crew can transfer to the other for a safe return to earth. The 800-ton ships have been assembled in orbit, during the year before the flight, from units carried up by space shuttles. Each ship is powered by three nuclear rockets. Two rockets provide the thrust needed to escape from the earth's gravity; the third

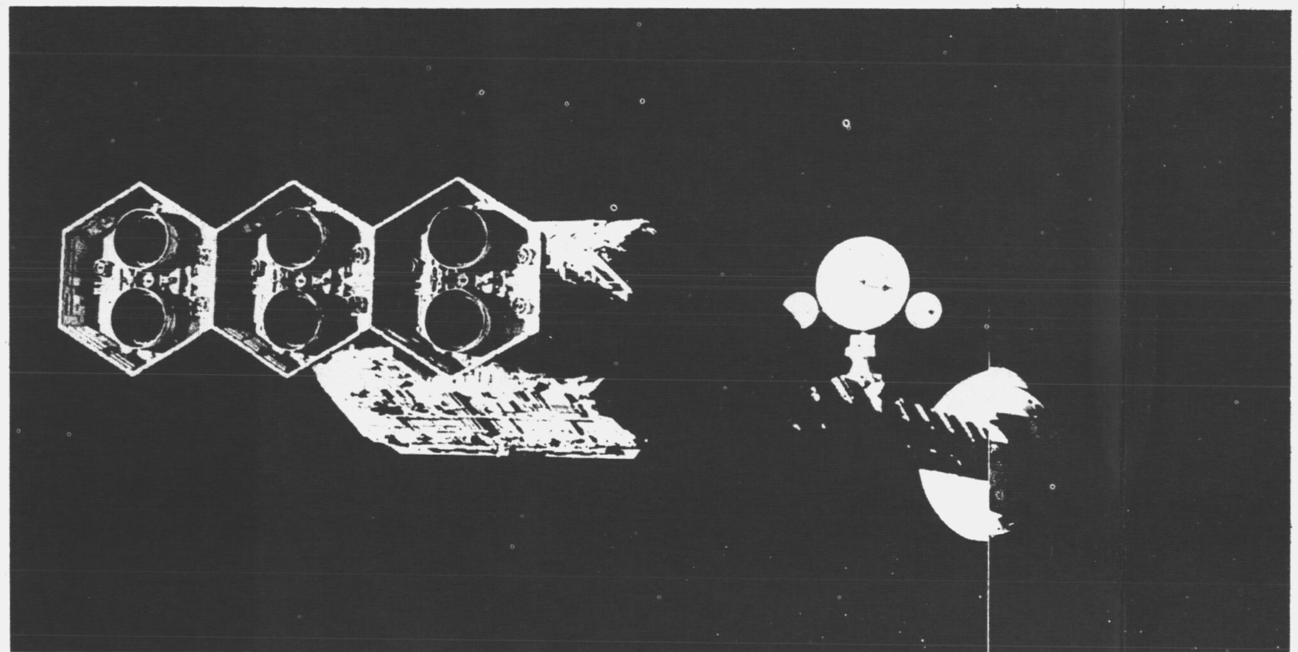
***The space shuttle and the space station play an important role in plans for down-to-earth applications of space flight during the nineteen-seventies, and are almost certain to be developed regardless of the pace of planetary exploration. The shuttle will cut the cost of space operations from between $1,000 to $10,000 a pound for delivery of freight into orbit to $10 or $20 a pound by the mid-eighties. With this price tag, the space shuttle can carry up men and materials for minor repairs to commercial satellites, or transport an entire satellite down from orbit for overhaul. Because of its cheapness per orbited pound, the space shuttle may also replace present-day boosters as the means for putting unmanned scientific satellites into orbit. It will be general workhorse of the space program.**

powers the interplanetary flight, the retro-burn for dropping into orbit around Mars, and the return trip to the earth. Rockets are strapped together side by side, so that the ships resemble giant three-barreled shotguns. Each barrel is 33 feet wide. The flanking barrels, 160 feet long, contain the nuclear rockets for the escape from the earth. The central barrel is 270 feet long. It contains the nuclear rocket for interplanetary flight, quarters for the crew of six and the Mars landing craft which will carry four men down to the surface of Mars and up again.

The ships have been fueled with liquid hydrogen during the previous week. Now they circle in orbit awaiting take-off. The take-off is smooth, in contrast to the roaring inferno of the Saturn launch. Luminous streams of superheated hydrogen jet from the outboard engines of each ship. Reacting to their backward push of 200,000 pounds, the ships spiral sluggishly away from earth orbit and nose into the solar wind. The 18-month journey has begun.

A quarter of a million miles from the earth, the two outboard rockets drop off from each craft and turn back toward the earth under remote control, to be refueled and serviced for the next Mars flight. The main craft continue on their way, now reduced to their cruising weights of 300 tons. For two days they fly in tandem, each crew fully occupied with spacecraft systems checks. Then, with the ships checked out for the interplanetary flight, the commanders undertake a delicate maneuver vital to the well-being of their crews during the long journey. They will dock the two ships stern-to-stern to form a single pencil-shaped craft 540 feet long. Slowly, they inch toward one another, cautiously feeling for the adapters. The link-up is successful. Small lateral thrustors set the long cylinder into a lazy spin at one revolution per minute, creating an artificial gravity force of one-sixth "g" in the crew cabins. Each man aboard has completed a qualifying course of six months at the Central Lunar Base and is grateful for the familiar feel of lunar gravity.

Life settles into the shipboard routine of systems checks, navigational fixes, eating, sleeping and study. The crews live and work in cylindrical modules 33 feet wide and 40 feet long, containing four levels. One module accommodates six men, but could accommodate 12 if required. Each man consumes two pounds of oxygen and one pound of food daily, plus 10 quarts of water for cooking, drinking and washing. Eight and a half quarts are recovered by daily recycling of wastes and condensation of atmospheric moisture. The remaining one and a half quarts come from the on-board water supply. Forty thousand pounds of oxygen, food and water will be consumed by the crews of the two ships during the journey, but double that amount is carried as a margin of safety. The psychological strains of the voyage are severe, but the crew have been tested for their stability by tours of duty in the space stations and at the Central Lunar Base.



Forecast. Not unlike the nuclear-powered Mars rockets envisioned by the author as possible by the end of this century, the craft Discovery, in "2001," takes off from earth orbit, headed for outer space.

The two ships coast to Mars, arriving in its vicinity eight months later. While still more than a million miles the ships separate and approach Mars, flying in tandem once more. Gradually they accelerate under the pull of the planet's gravity, with courses set for a close approach. As they whip past the planet at 7,000 miles an hour, a burn of the nuclear rockets reduces their speed and they drop into parking orbits. The crew of one ship has been designated for the descent to the surface. The other ship stands by for emergencies. The chosen crew members begin their preparations.

The four men in the landing team enter the MEM, an enlarged two-decked version of the lunar module, and descend to the surface, prepared to remain as long as two weeks. At the end of the first day, exploration in the vicinity of the landing site reveals nothing of interest. On the second day, the Mars Rover is taken out of its parking space in the lower level of the MEM, and two geologists begin the first of a series of extended traverses.

Three miles from the landing site, they pass a field littered with flat mounds of crumbling gray soil, which stand out against the brownish terrain. The mounds are 1 or 2 feet in diameter; none is more than 6 inches high. Have they discovered a new mineral? They remember nothing similar in the color photographs secured during the extensive unmanned photographic reconnaissance of the planet, prior to the manned flight. One of the geologists leaves the Rover and walks toward one of the gray clumps; five yards away, his shadow falls across it. He notices a barely perceptible movement. The clump is alive, but a form of life so desiccated that, when immobile, it seems to be composed of inanimate matter.

Using their shovels, the two men carefully pick up one of the smallest of the gray mounds, together with an inch or so of the underlying soil, and deposit it in the specimen compartment at the back of the Rover. Traverses on subsequent days reveal only one other locality containing a colony of the gray mounds. They are a sparse form of Martian life that escaped detection during the unmanned-reconnaissance phase of Mars exploration. They do not resemble lichens or other forms of life that grow in a dry, cold climate on the earth.

With their stay on the surface completed, the landing team returns to its ship — parked in orbit above—using the upper section of the MEM as the ascent rocket and the lower section as a launch pad. Under the forward thrust of the nuclear rocket, the two ships break out of the grip of Mars's gravity, rendezvous again, and commence the return leg of this journey. This leg will take ten months, two months more than the journey out, the extra time being required to catch up with the earth in its orbit. As the ships near home, they separate and drop into earth orbits. The Mars ships are parked, available for subsequent flights. The crews transfer to a waiting space shuttle for the return to earth.

The ungainly space shuttle descends into the atmosphere, belly up. When friction has slowed it down to 300 miles an hour, the pilot pitches the nose down into level flight and auxiliary jet engines roar to life. The craft speeds across the Pacific, crosses over Los Angeles, and descends to an isolated jetport in a Southwestern state.

As it comes to a halt at the end of the runway, cargo-bay doors in the top of the fuselage slide back. One end of the interior is sealed off and filled with carbon dioxide at a low pressure. A bank of lights shines weakly at the top of the sealed enclosure. The floor is covered with reddish Martian soil. A gray mound rests in the center. Occasionally the shadow of a passing crew member falls across the glassed-in porthole at the end of the enclosure, and the mound stirs uneasily.

Back in 1975, an unmanned laboratory deposited on Mars had picked up telltale traces of organic matter, residues of tentative, faltering steps along the path from nonlife to life. Nothing more was discovered in later unmanned explorations, but the first manned Mars expedition has been luckier. Men now know that the spontaneous generation of life is not an improbable event. When the discovery of the gray mounds was first announced from the surface of Mars eight months before, it seemed like a biological curiosity. Now the full impact of the discovery hits home: The galaxy must be teeming with life. Young, primitive planets, circling other stars, await our exploration. Older, advanced societies wait to welcome us into the galactic network of intelligence. The greatest experiences of Homo sapiens lie ahead of him.

WHY am I certain that men will make the trip to Mars? I believe it is inconsistent with the nature of life and the nature of man—as revealed by the record of the past—for the entire human species to rest forever content with existence on one planet or in one solar system. The history of life suggests that most individuals in a species remain in the environmental niche to which the species has become adapted. But the desire for comfort and security, as all other traits, varies from individual to individual. Certain individuals will always probe the limits of their environment. When does this probing become of major importance? When adverse forces in the environment exert a firm pressure on the population: Then the random probing is converted into a directed movement, and the adventurous few become the vanguard of a major evolutionary advance.

The last major development of this kind occurred 300 million years ago, when, in a time of seasonal drought, the fishes left the water and invaded the land to become the first air-breathing animals with backbones.

But not all fishes made the transition. Only those species equipped with stumpy fins for walking, and with lungs as well as gills for breathing, could do so; and among these favored species, only the few doubly favored individuals who were especially well suited for land life—thanks to the variations that occur throughout nature—could survive, flourish and propagate their desirable traits. From those few, favored by a suitable body apparatus, and perhaps by an unusual measure of curiosity and fortitude, are descended all the air-breathing back-boned animals that now inhabit the earth.

Today, the most advanced forms of life on the earth are again threatened by adverse circumstances. The circumstances are not the product of external, natural forces this time, but are of our own making, and cultural in origin. They include the threat of extinction in nuclear warfare, the threat of overpopulation, and the subtler threat contained in an excess of leisure time.

These factors, combined with the psychological impact of a shrinking globe made yet smaller by jet aircraft and communications satellites, provide favorable circumstances for converting the tentative explorations of a few astronauts and cosmonauts into the vanguard of a more general move of the species away from the planet. Unless the course of evolution is interrupted or terminated by a nuclear or ecological catastrophe, we will inevitably move into the empty environmental niche that space travel has made accessible.

Which of us will make the move? Not everyone. Just as 300 million years ago, most fish remained in the water, in tomorrow's world most of us will stay on the earth. Space is not a comfortable place for earth-adapted life, any more than the land was comfortable for early amphibians. But a small percentage of the human species is equipped—by virtue of those random variations that provide the raw material on which natural selection acts — to function better in a zero-gravity or low-gravity environment than the majority of human beings. A small percentage is also restless, inquisitive, innovative, continually seeking out challenges and testing the limits of the environment.

That fraction will leave us, for brief intervals at first and then for longer and longer times. They will move out to become a small, hardy population on Mars. Within a few decades of the year 2000, a pioneering band of men—and women — will be living on Mars, trying to make a go of things, trying to make the desert bloom, testing their stamina and ingenuity against the challenges of life on a new planet. Children will be born on Mars. Later, the spacefarers will go beyond Mars and beyond the solar system. Some day they will find the earth and its debilitating gravitational pull as difficult a place in which to survive as today's land-adapted men find the water out of which the ancestral fishes emerged 300 million years ago. Eventually, they will constitute a new species, evolved out of Homo sapiens, but linked to the ancestral planet only by sentiment. ■